# MDAG.com Internet Case Study 57

# MDAG-com Case Study 57 - Water Quality of Full-Scale Mining and Non-Mining Drainages is a Fractal Wave

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www.mdag.com/case_studies/cs57.html

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## 1. Introduction

The assessment of water quality in full-scale drainages at existing minesites[1], and the prediction of future quality, is based on old science and old techniques used for many decades. For example, humidity cells were first used around 1962, more than a half century ago. For the most part, minesite-drainage assessment and prediction are rather stagnant and not progressing quickly.

Imagine how much faster our understanding of minesite-drainage chemistry, and of water quality in general, would advance if we could adapt and use information and techniques from other sciences and various fields of mathematics.

When we think of water draining from a minesite component or non-mining catchment, we think of the occasional sampling of that water, such as every month or every week. If someone asked, “What was the arsenic concentration for August?”, the monthly analysis for August would tell us, or the average of the four weekly concentrations in August would tell us. However, would it do so accurately? What if this approach were inaccurate and misleading? This document is a challenge to the half-century and more of existing, detailed minesite-drainage studies.

Imagine sampling the water quality of a drainage once a week, once a day, once an hour, and once a minute. Would they all tell you about the same thing? They would not, if the time series displayed a fractal distribution.

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[1] Another name for this minesite-drainage quality or chemistry is ML-ARD, which is an acronym for Metal Leaching and Acid Rock Drainage. However, its usage shows it is more comprehensive, and includes aqueous geochemistry and inorganic water contamination.

## 2. Temporal Waves and Fractal Distributions

A simple example of a fractal, in spatial dimensions rather than time, is the measurement of the length of Canada's coastline. If you measured the length of the coastline with a straightedge or "ruler" representing 1000 km (Figure 1), you would come up with a coastline length. However, you would not be able to measure the edges and perimeters of many inlets, fjords, and river outlets. If you had a ruler that was 10 km long, you could now measure the coastlines of some larger inlets and fjords, and thus the measured coastline would now be longer.

Let's keep going, that is, let's keep using shorter rulers. If you had a ruler that was 10 m long, now you could get into virtually all inlets and fjords (Figure 1), and the measured coastline would be even longer. However, you would still miss the additional coastline caused by some boulders less than 10 m sticking out into the water and by some small indentations. These small features can significantly increase the measured coastline because they are so abundant.

**Figure 1. Measuring Canada's coastline with a ruler; as the length of the ruler decreases, the measured length of coastline increases, reflecting its fractal distribution.**

So what is the real length of Canada's coastline? It depends on the length of your ruler; the coastline keeps increasing as your ruler gets shorter. This is an example of a fractal.

Can this apply to time series also? Can the maximum measured concentration and the calculated average concentration increase as the time spacing between sampling (e.g., weekly vs. hourly) decreases, that is, as the time "ruler" gets shorter? What would such a time series look like when plotted? The answer is: a complex wave.

Think of aqueous concentrations, and the flow of water carrying those concentrations, as complex waves that rise and fall in complex patterns as time passes. This would require us to abandon old ways of thinking of water quality in discrete or steady steps, and adopt new ways.

Fortunately, waveforms have been studied in other sciences for centuries. There are sound waves, light waves, radio waves, ocean waves, and so on. If drainage chemistry is also a waveform, then much of what is known about waves, and how waves are mathematically characterized, can be adapted to water quality in drainage.

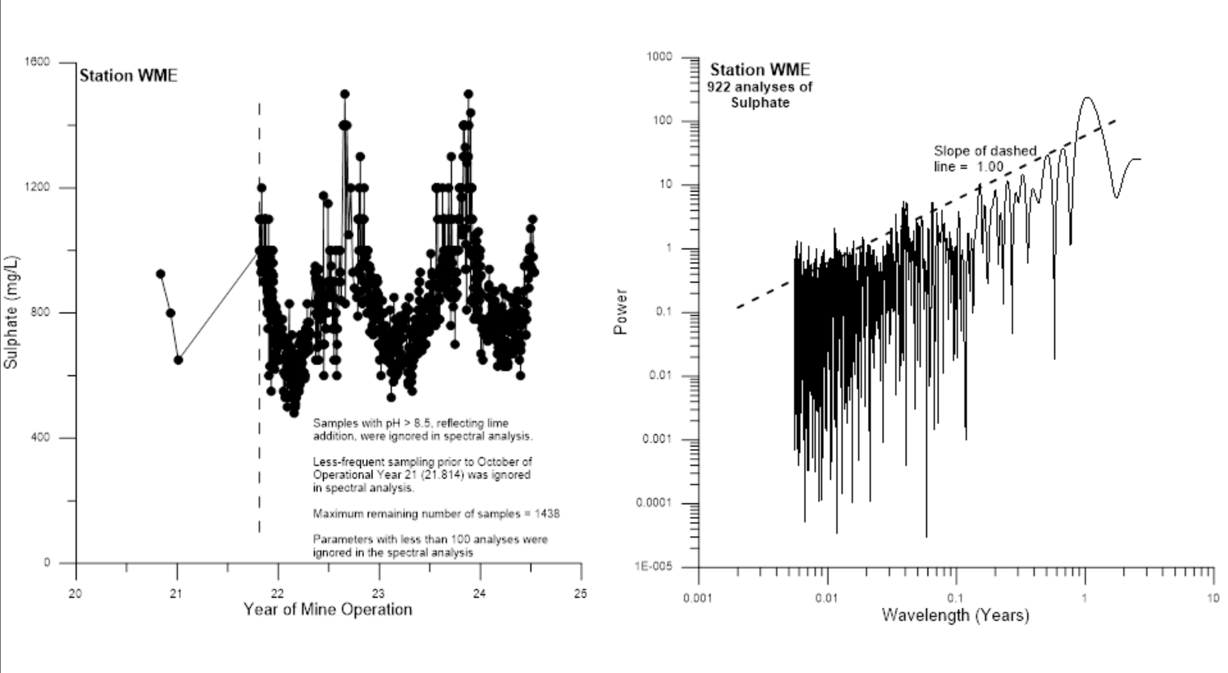

**Figure 2. (Left side) a time series of aqueous sulphate in minesite drainage, showing a complex wave pattern; (right side) the left side mathematically converted to a plot of wavelength on the x-axis and the "spectral" power of each peak on the y-axis, showing the complex wave on the left is composed of many superimposed waves of various wavelengths (x-axis) and amplitudes (proportional to power on the y-axis).**

Here is an example. On the left side of Figure 2 is a time series of sulphate in water draining from a full-scale waste-rock pile. It is not a simple wave. Instead, there are many waves of various heights (amplitudes) and durations (wavelengths) all combined into one complex wave through time.

Because the left side of Figure 2 is a wave, we can use mathematical techniques to separate out all the waves causing that complex one. For example, Fourier analysis was developed about 200 years ago for this purpose, and the right side of Figure 2 shows the results. Those "spectral" peaks on the right side represent individual contributing waves. They have certain wavelengths on the x-axis. On the y-axis, the heights of the peaks represent their power in affecting the combined complex wave.

Notice that a straight line connects the tops of the peaks on this log-log plot on the right side of Figure 2. This is a sign of a fractal distribution.

The straight-line slopes in full-scale drainages can typically range from values of zero to two (Aubert et al., 2013; Morin, 2016). The right side of Figure 2 has a slope of 1.0, which is often called a "1-over-f slope" or "pink noise". These 1-over-f slopes, according to regular mathematics, are not possible, because they suggest the system is precariously balanced on a fine edge between stability and chaos that cannot last for long.

Yet, 1-over-f slopes do persist for long times. And they have been documented in many sciences and arts, like earthquakes and their aftershocks, landslides, light from quasars, DNA sequences, weather data such as temperature and precipitation, highway traffic flow, river flow, tides, heart beats, neural activity, biologic evolution, solar flares, psychological models of mental states, electrical current in solid-state devices, epidemics, variations in musical styles, patterns in abstract art, insulin uptake by diabetics, economic trends, forest fires, application of automotive paint, cavitation in pumps, and drainages from mining and non-mining catchments. There are thousands of published papers on 1-over-f slopes, and they remain a major topic of investigation. People studying minesite drainage and water quality could learn much from this existing work[2].

An important question is whether fractal time series, including 1-over-f slopes, are common in water-quality time series of full-scale non-mining and minesite drainages. Answering this question requires special databases with specific intensities and durations of monitoring. Unfortunately, there are few such databases.

About a dozen databases show that fractal time series are always found in full-scale drainages from non-mining catchments, and 1-over-f slopes are "ubiquitous" in some (Aubert et al., 2013, and references therein). For minesite drainage, four databases show that fractal time series are typically seen, with 1-over-f slopes observed but not ubiquitous (Morin, 2016). Based on these few examples, fractal time series, including some 1-over-f slopes, should be expected in most full-scale mining and non-mining drainages.

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[2] http://www.mdag.com/1-over-f-slopes.html

## 3. The Importance of Recognizing and Addressing Fractal Time Series

All this about waves, 1-over-f slopes, and frequency of sampling is scientifically and mathematically interesting. However, an important question is whether this has any significance for "real-world" water quality, environmental contamination, and ecosystem damage. The answer is: yes, and there can be major implications.

As an example, Figure 3 shows electrical conductivity measured at the same monitoring location, but once a week in the upper diagram and once an hour in the lower. Electrical conductivity (EC) is generally proportional to total dissolved solids and aqueous concentrations of some contaminants.

Notice in the upper diagram of Figure 3 that EC (1) remains relatively constant from sample to sample, (2) the maximum concentration is relatively low and close to the other values, and (3) the average of all values is close to each measured one. If a minesite were required to sample its water quality every week like this, it would report to regulatory agencies that EC is relatively constant and (in this case) remains below the regulated maximum limit.

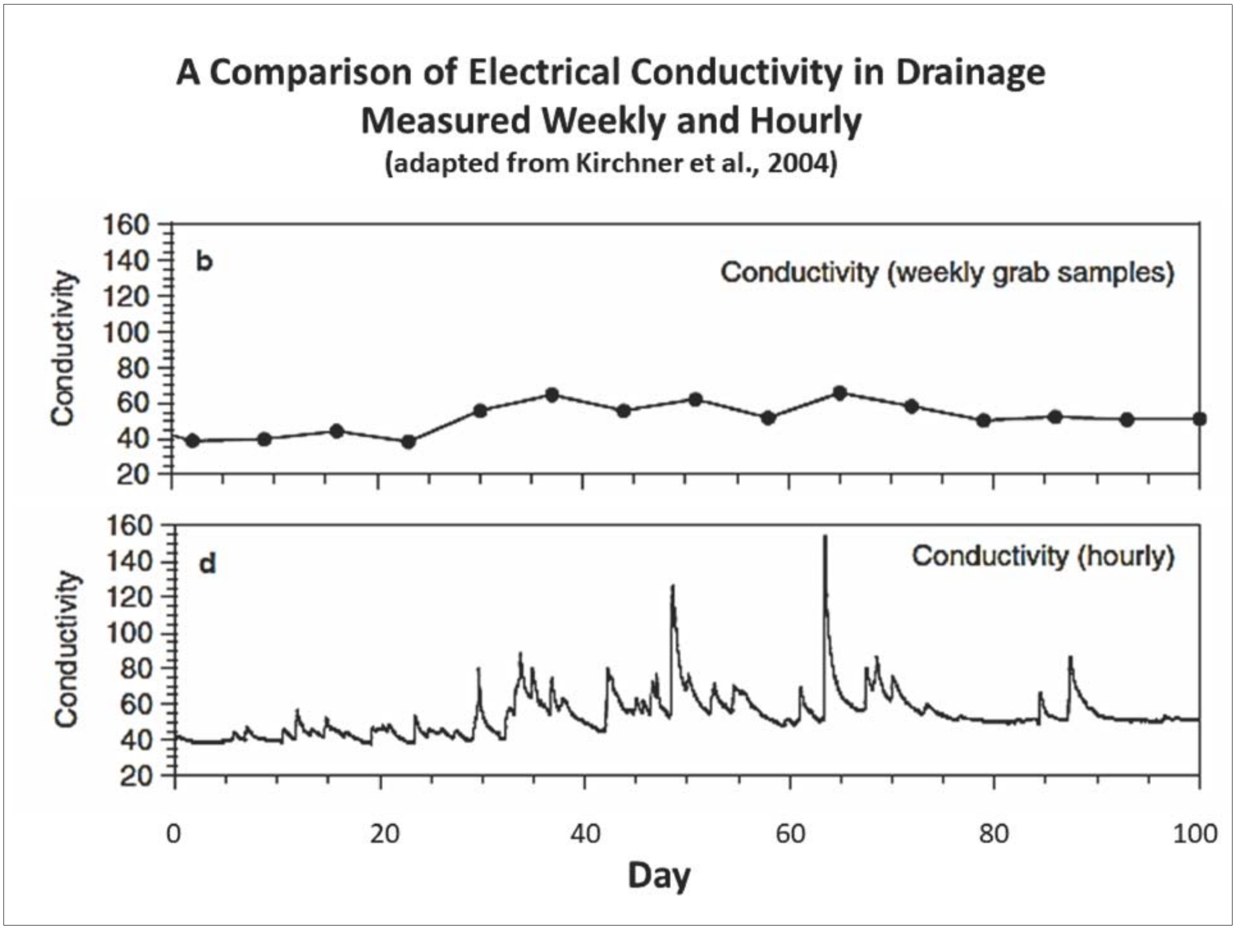

**Figure 3. An example of electrical conductivity measured in drainage at the same location, but measured (top) only once a week and (bottom) once an hour; the more frequent hourly monitoring shows a higher maximum concentration, higher average concentration, and higher cumulative loading, typical of fractal distributions in drainage.**

This is the truth – the minesite would not be lying. However, is it reality?

The hourly measurements would say EC (1) is not relatively constant, (2) occasionally exceeds the regulated maximum limit, (3) has a higher average, and (4) has long-term released contaminant loadings (like kilograms/month) greater than shown by weekly measurements. As a result, reality and water-quality information change as the frequency of sampling changes, with higher-frequency monitoring more closely approaching reality.

Thus, full-scale minesite drainage is typically a fractal time series when sufficient data are collected to confirm this. As with measuring a coastline, the smaller the ruler (that is, the smaller the time spacing between samples), the higher will be the measured maximum contaminant concentration, the average, and the sum. In other words, (1) higher contaminant concentrations are released, and (2) cumulatively a higher loading is released, than would be indicated by less frequent sampling.

Various life forms and species react differently to occasional peaks of contaminant release. Some are not affected by a short-term peak. Other life forms are affected by the total cumulative exposure, basically the sum of all values including peaks[3]. Others take in contamination and release it back to the environment very slowly, so that peaks can adversely affect them also for extended periods.

Therefore, knowing that full-scale water quality and minesite drainage are typically fractal waveforms means that we have to re-think how we assess and predict them. In turn, new approaches to the assessment of ecological damage, toxicity, and risk are needed for water quality and drainages. This requires a major shift in thinking, but it is made much easier by many other sciences that have studied waveforms and 1-over-f slopes for decades.

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[3] http://www.mdag.com/case_studies/cs49.html

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